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# Analysis of South Korea's economic growth, carbon dioxide emission, and energy consumption using the Markov switching model

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ABSTRACT

Recently, many countries have been making an effort to reduce their carbon dioxide ($CO_2$) emission, and as part of such effort, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol in 1997. South Korea is very likely to be included in the second batch of countries that must reduce their greenhouse gas emission after the end of the implementation of the Kyoto Protocol in 2012. Reducing the country's $CO_2$ emission, however, can have an impact on the economy. Therefore, in this study, the correlations between South Korea's economic growth, $CO_2$ emission, and energy consumption were analyzed. The analysis period was from Q1 1991 to Q4 2011, and the analysis methods that were used were regression analysis for the relational analysis among the various overall indices, and the Markov switching model for a more detailed analysis. The results of the analyses showed that South Korea's economic growth and $CO_2$ emission were coincidental. The correlation analysis of the country's economic growth and energy consumption showed a significant correlation between economic growth and fossil fuels, which emit $CO_2$, such as coal in the industrial sector, petroleum products in the industrial and transportation sectors, and liquefied natural gas (LNG) in the residential/ commercial and industrial sectors. It is expected that the results of this study will pave the way for the conduct of various researches on controlling the country's $CO_2$ emission management, and for suggestions for such to be given, such as policies for reducing the energy consumption in each sector, using the methodology proposed in this study.



**Contents**



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## 1. Introduction

For the last few decades, the global economic growth has caused various side effects, including climate changes due to global warming. Thus, the international interest in carbon dioxide ($CO_2$) emission is increasing. In 1997, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol, based on which many countries have exerted various efforts to reduce their $CO_2$ emission. As the implementation of the Kyoto Protocol will end in 2012, the world is now focusing on the post-Kyoto Protocol scenario. In particular, the world is waiting to see which countries will be included in the batch of countries that must reduce their greenhouse gas emissions in the post-Kyoto Protocol.

South Korea has achieved rapid economic growth over the last few decades. Its gross domestic product (GDP), which was USD 3892 million in 1960, soared to USD 1,116,247 million in 2011, making South Korea the 15th largest economic market in the world [1]. At the time that the Kyoto Protocol was adopted, South Korea was still considered a developing country and was thus not designated as a country that must reduce its greenhouse gas emission. South Korea's recent economic growth, however, is likely to make UNFCCC consider putting the country on the list of the second batch of countries that must reduce their greenhouse gas emission. Recently, many studies have begun considering the economic impact of each country's $CO_2$ reduction, and to minimize such impact, many studies have made an effort to determine the correlation between economic growth, $CO_2$ emission, and energy consumption [2].

Therefore, this study examined the correlation between South Korea's economic growth, $CO_2$ emission, and energy consumption. The analysis period spanned 84 quarters, from Q1 1991 to Q4 2011. In the case of $CO_2$ emission, because a sufficient amount of data on it is difficult to acquire as it is reported as annual data, it was limited in this study, and it was estimated from the amount emitted based on the primary energy consumption presented in a previous study [3].

For the progression of this study, regression analysis was used for identifying correlations between the overall indices, and the Markov switching model was used for a more detailed analysis. With the use of these two analysis methods, the correlation between economic growth and $CO_2$ emission was first analyzed, after which the correlation between primary energy consumption, which was used in estimating $CO_2$ emission, and economic growth was determined. Finally, the factors that affect the consumption of each energy source were identified and examined through the analysis of the trends of consumption of the energy sources related to economic growth, among the primary energy sources.

## 2. Motivation

A number of studies have been conducted that aimed to analyze the correlation between economic growth, $CO_2$ emission, and energy consumption. First, via autoregressive distributed lag (ARDL) cointegration analysis, Ozturk and Acaravci [4] analyzed the long-run and causal correlation between Turkey's $CO_2$ emission, energy consumption, and gross domestic product (GDP) between 1968 and 2005. The results that they obtained in their study showed that Turkey's $CO_2$ emission and energy consumption hardly affected its GDP. The results also showed that the country's GDP had only a slight impact on its $CO_2$ emission, and there was little evidence of a causal correlation between the country's $CO_2$ emission and its energy consumption.

Menyah and Wolde-Rufael [5] analyzed the correlation between the United States' $CO_2$ emission, its renewable- and nuclear-energy consumption within the period from 1960 to 2007 and GDP, using the granger causality test. The analysis results showed a bidirectional causality between the country's GDP and $CO_2$ emission, and a unidirectional causality between its GDP and renewable-energy consumption. On the other hand, no causality between the country's GDP and nuclear-energy consumption was shown. Finally, it was found that the country's nuclear-energy consumption affected its $CO_2$ emission but that its renewable-energy consumption did not.

Lotfalipour et al. [6] analyzed the correlation between Iran's GDP, $CO_2$ emission, and fossil fuel consumption within the period from 1967 to 2007, using the unit root test and the Granger causality test. The results showed a unidirectional causality between the country's consumption of petroleum products and natural gas, which emit $CO_2$, and the country's GDP, but no causality was shown between the country's total fossil fuel consumption and its $CO_2$ emission.

Hatzigeorgiou et al. [7] analyzed the correlation between Greece's $CO_2$ emission, GDP, and energy intensity (primary energy consumption per GDP) within the period from 1977 to 2007, using the multivariate co-integration and granger causality tests. The results showed a unidirectional causality between the country's GDP and its energy intensity or $CO_2$ emission.

Pao et al. [2] analyzed the correlation between Russia's $CO_2$ emission, energy use, and GDP within the period from 1990 to 2007, using co-integration and granger causality tests. Their study results showed that while there was a long-run equilibrium correlation between the country's $CO_2$ emission and Energy use, between the country's $CO_2$ emission and GDP. The correlation between Russia's $CO_2$ emission and energy use was elastic, and it was inelastic between the country's $CO_2$ emission and GDP.

Glasure and Lee [8] examined the causality between energy consumption and GDP in South Korea and Singapore from 1961 to 1999 using the co-integration and error-correction tests. In this study, a bi-directional causal relationship between energy consumption and GDP in South Korea was discovered.

Oh and Lee [9] analyzed the causal relationship between the energy consumption and economic growth of South Korea from 1970 to 1999 using the vector error correction model (VECM). This study used annual data on real GDP, energy consumption, capital, and labor and uncovered a long-term bi-directional causal relationship and a short-term unidirectional causal relationship between energy consumption and real GDP. On the other hand, another study of Oh and Lee [10] wherein data from Q1 1981 to Q4 2000 and VECM were used showed no causal relationship in the short term and a unidirectional causal relationship in the long term between energy consumption and real GDP.

Yoo [11] also analyzed the short- and long-term causality between electric consumption and economic growth from 1970 to 2002 using the co-integration and error-correction models. This study showed a strong unidirectional causality of electric consumption to economic growth.

Chen et al. [12] analyzed 10 Asian countries including South Korea to estimate the relationship between GDP and electric consumption from 1971 to 2001 using the co-integration and error-correction models. This study found a long-term causal relationship between real GDP and electric consumption, but not the reverse.

Niu et al. [13] analyzed eight Asia-Pacific countries including South Korea to evaluate the causality among energy consumption, GDP growth, and carbon emissions from 1971 to 2005 using panel data analysis. In this study, South Korea and three other countries – Australia, New Zealand, and Japan – were analyzed as developed countries, and it was concluded that the GDP and energy consumption of South Korea are correlated."

In all the aforementioned studies except for the study of Oh and Lee [10], the analysis was conducted using annual data. It is generally recommended that for multivariate data analysis, at least 50–100 data be used [14] because insufficient data may affect the reliability of statistical analysis. Besides the number of data, the results of the above studies may show the correlation between economic growth, energy consumption, and $CO_2$ emission only numerically, and do not offer a visual representation of the correlation within a specific period. Furthermore, the study of Oh and Lee [10] did not analyze the causality between $CO_2$ emissions and economic growth, although the study was conducted using quarterly data.

Meanwhile, Kim et al. [3] estimated the monthly fossil fuel energy consumption data in South Korea as $CO_2$ emission according to the IPCC Guidelines. Moreover, not using the GDP, which is a quarterly data, they aimed to overcome the limitation of an insufficient number of data by using the monthly industrial-production index, which allowed them to acquire sufficient time series data. The linear granger causality test showed no correlation between $CO_2$ emission and economic growth whereas the nonlinear granger causality test showed a bidirectional causality between the two. It was also estimated that South Korea would suffer a huge economic impact from $CO_2$ emission reduction.

While the above study was able to increase the level of reliability of its statistical-analysis results by using a sufficient amount of data, it did not show the factors' correlation by period and only numerically expressed such correlation. On the other hand, this study that was conducted using the Markov switching model was able to analyze the correlation among $CO_2$ emissions, energy consumption, and economic growth from the graphical and numeric results, using periodical information.

## 3. Markov switching model

The trend analysis of each time series data analyzed in this study uses the Markov switching model proposed by Hamilton [15–17]. The Markov switching model can probabilistically and visually analyze a business cycle using time series data, and has been widely used as an analytical tool in economics and finance [18]. The method was also reported to be used in analyzing the cycle of time series data in areas other than economics and finance, such as in traffic flow [19].

The Markov switching model is generally divided into the Markov switching random walk (MS-RW) model and the Markov switching autoregressive (MS-AR) model, and depending on how to divide the state, two- and three-state models are used. "In this study, the MS-RW model was used for the analysis under the same conditions because the degree of the autoregressive model of the time series data that was used in this study was defined using Eviews, a statistical simulation program, and calculated the zero degree without GDP. The degree of the autoregressive model of the GDP time series data was deduced as the first degree, AR (1)." Also used was the two-state model, which divided the state into the upward and downward states.

In the MS-RW model, the process of state change at each point is determined by the first Markov stochastic process. In terms of the movement of the time series, it is assumed to be in accordance with the stochastic process of random walk with drift, as shown in eq. (1).

$$y_t - \mu_{s_t} = y_{t-1} - \mu_{s_{t-1}} + \text{z.epsiv;}_t,\ \text{z.epsiv;}_t \sim i.i.d.N\left(\mu_{s_t}, \sigma^2_{s_t}\right) \tag{1}$$

where $s_t$ is a state indicator at the point of t time. $y_t$ is the conditional expected value of time series corresponding to a state at the point of t time, $\mu_{s_t}$ is a trend term according to the state and $\sigma^2_{s_t}$ is a distribution term according to the state. In the case of a two-state model, the upward state is presented as 1 and the downward state as 2. Thus trend terms of two-state model are $\mu_1$ and $\mu_2$ and distribution terms are $\sigma^2_1$ and $\sigma^2_2$.

In Eq. (1), the time series information ($y_t$) at the point of $t$ time represents the changes, such as log change rate between the time points of the time series information ($Y_t$) of the analyzed objects, as shown in Eq. (2) [18, 20, 21].

$$y_t = (\ln(Y_t) - \ln(Y_{t-1})) \times 100 \tag{2}$$

It is assumed that the present state ($s_t$) is followed by the first Markov chain, which is influenced only by the most recent state ($s_{t-1}$).

$$P\{s_t = j | s_{t-1} = i, s_{t-2} = k, \ldots\} = P\{s_t = j | s_{t-1} = i\} = p_{ij} \tag{3}$$

where $p_{ij}$ (transition probability) is the probability of transitioning from the most recent state (state $i$) to the present state (state $j$). In the case of two-state model, transition probabilities are $p_{11}$, $p_{12}$, $p_{21}$ and $p_{22}$.

The transition probabilities of the most recent and present states, which are determined by the Markov chain, can be expressed for about two states using the transition probability matrix ($P$), as shown in Eq. (4).

$$P = \begin{bmatrix} p_{11} & p_{21} \\ p_{12} & p_{22} \end{bmatrix}$$
$$\text{where } p_{i1} + p_{i2} = 1 \tag{4}$$

The conditional probability vector $\hat{\xi}_{t+1|t}$ at the next state ($s_{t+1}$) can be obtained by multiplying the transition matrix ($P$) by the conditional probability vector $\hat{\xi}_{t|t}$ at the present state ($s_t$), as shown in Eq. (5).

$$\hat{\xi}_{t+1|t} = P \times \hat{\xi}_{t|t} \tag{5}$$

In the case of two-state model, the parameters of $\hat{\xi}_{t|t}$ are trend terms $\mu_1$ and $\mu_2$, distribution terms $\sigma^2_1$ and $\sigma^2_2$, and transition probabilities $p_{11}$ and $p_{22}$. The parameters can be estimated using the logarithm likelihood function.

## 4. Research methodology

### 4.1. Data collection and processing

#### 4.1.1. Data collection

This study requires GDP, which shows economic growth, and $CO_2$ emission data. As has been mentioned, at least over 50 time series data (over 100, if possible) should be acquired for a more reliable multivariate time series analysis [14]. Unlike GDP,

**Table 1**
IPCC carbon emission factors.

| Fuel | Anthracite | Bituminous Coal | Gasoline | Kerosene | Diesel | Residual fuel oil | Naphtha | LPG | LNG |
|---|---|---|---|---|---|---|---|---|---|
| Carbon emission factor (C ton/TOE) | 1.100 | 1.059 | 0.783 | 0.812 | 0.837 | 0.875 | 0.829 | 0.713 | 0.637 |

however, whose data is reported quarterly or annually, enabling the acquisition of sufficient time series data, it is difficult to acquire sufficient time series data for $CO_2$ emission, which is usually reported as annual data. For example, the data on South Korea's $CO_2$ emission provided by the World Bank, number less than 40 as the starting point of the time series data is 1971 [1]. Therefore, in this study, the seasonally adjusted GDP quarterly data from Q1 1991 to Q4 2011 were collected using the economic-statistics system of the Bank of Korea [22], and the quarterly $CO_2$ emission data were derived by collecting the monthly primary energy consumption data from January 1991 to December 2011 reported by Korea Energy Statistics Information System [23]. Section 4.1.2 is a detailed description of the $CO_2$ emission data extraction process that was used in this study.

**Table 2**
Fossil fuel classification in primary energy consumption.

| Classification 1 | Classification 2 | Classification 3 |
|---|---|---|
| Coal | Anthracite | Domestic |
| | | Imports |
| | Bituminous coal | Coking |
| | | Steaming |
| | Gasoline | N/A |
| | Kerosene | N/A |
| | Diesel | N/A |
| Petroleum products | Residual fuel oil | N/A |
| | Naphtha | N/A |
| | LPG | N/A |
| | Others | N/A |
| LNG | N/A | N/A |

#### *4.1.2. $CO_2$ emission calculation*

The IPCC Guidelines recommends three levels of $CO_2$ emission estimation methods, from tier 1, the most basic methodology, to tier 3, the most detailed methodology. Compared to tiers 1, 2 and 3 were the methodologies that reflect the detailed conditions of the target country. The accuracy and precision of the $CO_2$ emission estimation increase from tier 1 to 3 [24]. The annually reported $CO_2$ emission in South Korea is estimated by the IPCC Guidelines, using tier 1. Some areas that require more detailed statistics use tier 2 [25]. The annual $CO_2$ emission data estimated as such are reported generally two to three years later than the years to which the data pertain. For example, South Korea reported the 2007 estimates in 2010. The $CO_2$ emission by energy consumption is actually only 90% of the $CO_2$ emission extracted from the final energy consumption. Resulting from the conversion of the primary energy consumption, the final energy consumption does not allow fast data creation and is thus reported in the form of annual data. Therefore, the $CO_2$ emission data that were used in this study were limited to the $CO_2$ emission generated from the primary energy consumption, identical to the methodology used in acquiring the sufficient time series data in a previous study [3]. The $CO_2$ emission was calculated using tier 1, the basic methodology that can be commonly implemented worldwide [24], and the carbon emission factor (Table 1) [25].

First, the energy sources that are primarily consumed are divided into six types: coal, petroleum products, liquefied natural gas (LNG), hydro, nuclear, and other types of energy. Among these, coal, petroleum products, and LNG are fossil fuels that emit $CO_2$. The consumption of each of these energy sources is shown in Table 2.

The consumption of each energy source was converted into ton oil equivalent (TOE) according to the conversion equivalents of calorific values by energy source (refer to Table 3) based on Article 15(1) of the Energy Act Addenda announced by the Ministry of Knowledge Economy in 2006, and was calculated as $CO_2$ emission using the IPCC carbon emission factor (refer to Table 1).

#### *4.1.3. Seasonally adjustment*

The quarterly GDP, the primary energy consumption and the $CO_2$ emission data extracted from the primary energy consumption should go through seasonal adjustment, allowing accurate analysis by removing the seasonal fluctuations that each time series data may have [26]. One of the most widely used methods of seasonal adjustment involves the use of X-12-ARIMA, developed by Census Bureau in the U.S. In South Korea, the seasonal adjustment of time series data, including GDP, reported by the Bank of Korea, uses BOK-X-12-ARIMA, a revised version of X-12-ARIMA [27]. In this study, the U.S. Census Bureau's X-12 methodology, based on EViews, a statistical program, was used.

### *4.2. Economic growth and $CO_2$ emission*

#### *4.2.1. Regression analysis of economic growth and $CO_2$ emission*

To determine the correlation between economic growth and $CO_2$ emission, regression analysis was first conducted in this study. A similar study in the past used the autoregressive distributed lag (ARDL) model as it considered that GDP, which showed the level of economic growth of a country, would be affected by the GDP in the previous year [4]. In this study, however, the correlation between the two was determined using simple regression analysis because the quarterly seasonally adjusted GDP data are not affected by past time series data.

Prior to the regression analysis, as the time series data that had been collected during the 84-quarter period had different units according to the indicator, they had to be normalized. There is no existing standard, however, on which whether a particular standardization method is good can be based. In most studies, the $Z$-score is used as a standardization method, as shown in Eq. (1), which follows a normal distribution with an average of 0 and a standard deviation of 1.

$$Z\text{-score} = \frac{x_i - \bar{x}}{s} \tag{1}$$

where, $x$ is a raw score to be standardized, $\bar{x}$ is the mean of the population, and $s$ is the standard deviation of the population.

$Z$-score can be immediately to be used to obtain standardization data. For easier analysis, the $Z$-score can be converted into a percentage by multiplying the standard normal cumulative distribution function value corresponding to each $Z$-score in normal distribution by 100, as shown in Eq. (2) [28]. In this study, $Z$-score converted into a percentage was used for standardization

$$\text{Percentile score} = f(z) \times 100 = \frac{1}{\sqrt{2\pi}} e^{-z^2/2} \times 100 \tag{2}$$

Using standardized data, regression analysis of GDP and $CO_2$ emission was conducted, and the results are shown in Table 4. Before the analysis, the $R$-squared value resulting from the

**Table 3**
Energy conversion factors (oil equivalent).

| Fuel (Unit) | Petroleum products | | | | | | Coal | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gasoline (ℓ) | Kerosene (ℓ) | Diesel (ℓ) | Residual fuel oil (ℓ) | Naphtha (ℓ) | LPG ($Nm^3$) | Domestic anthracite (kg) | Imports anthracite (kg) | Coking bituminous (kg) | Steaming bituminous (kg) | LNG (kg) |
| Energy conversion factors (oil equivalent) | 0.800 | 0.880 | 0.905 | 0.990 | 0.805 | 1.500 | 0.465 | 0.655 | 0.620 | 0.700 | 1.300 |

**Table 4**
Regression analysis result between GDP and $CO_2$ emission.

| Variable | Coefficient | Std. error | *t*-Statistic | Prob. |
|---|---|---|---|---|
| C | −2.554419 | 1.039287 | −2.457858 | 0.0161 |
| $CO_2$ emission | 1.033351 | 0.017694 | 58.40031 | 0.0000 |
| *R*-squared | 0.976522 | Mean dependent var | | 49.77102 |
| Adjusted *R*-squared | 0.976235 | S.D. dependent var | | 31.30979 |
| S.E. of regression | 4.826641 | Akaike info criterion | | 6.009700 |
| Sum squared resid | 1910.310 | Schwarz criterion | | 6.067577 |
| Log likelihood | −250.4074 | Hannan–Quinn criter. | | 6.032966 |
| *F*-statistic | 3410.596 | Durbin–Watson stat | | 0.548785 |
| Prob (*F*-statistic) | 0.000000 | | | |

Dependent variable: GDP; method: least squares; sample: 1991Q1 2011Q4; included observations: 84.

regression analysis was significant at 0.976522. Here, the standardized regression coefficient of the independent variable $CO_2$ emission, which explains the dependent variable, was 1.033351. Thus, as the GDP and $CO_2$ emission showed identical movements, it can be said that there is a close correlation between them. The regression analysis, however, only showed that there is a correlation between GDP and $CO_2$ emission and did not reveal the type of correlation that the two have, and at what particular period. Therefore, additional time series analysis was conducted using a Markov switching model.

### 4.2.2. Markov switching model execution

Owing to the limitations of regression analysis, another analysis was conducted using a Markov switching model. In this process, two time series data, GDP and $CO_2$ emissions, were calculated as log change data, as mentioned in Section 3, before the execution of the Markov switching model." Fig. 1 shows the result of the analysis: the rising tendency of one of the two states extracted via time series analysis.

The GDP and $CO_2$ emission time series data analysis using the MS-RW model showed that the two time series data were coincidental. In Q1 1998, however, the probability of the GDP and $CO_2$ emission fell to 0 due to the financial crisis in South Korea at the end of 1997. Moreover, the GDP in 2008 showed a depression due to the subprime mortgage crisis in the U.S., and the global economic crisis, whereas $CO_2$ emission did not show the same trend. This may be due to the fact that while GDP is coincidental with $CO_2$ emission, $CO_2$ emission does not respond to the economic impact of the external factors in South Korea as it does to the economic impact of the internal factors.

The characteristics of each time series (based on the parameter estimation results) extracted from the MS-RW model show fluctuations of both time series data in the rising tendency ($\sigma_1^2$) rather than in the falling tendency ($\sigma_2^2$). Moreover, $p_{11}$, the continuity in the rising tendency, was close to 1 (0.9677 and 0.9847) while $p_{22}$, the continuity in the falling tendency, was 0.3999 or 0.4922, which show that the state did not continue and was transformed into a different state (refer to Table 5).

## 4.3. Economic growth and energy consumption

### 4.3.1. Regression analysis of economic growth and energy consumption

The regression analysis results and MS-RW model showed that economic growth (based on the GDP) and $CO_2$ emission (extracted from the primary energy consumption) were coincidental. The $CO_2$ emission data that were used in this study were derived from the primary energy consumption values. Therefore, in this study, the energy sources whose consumption was related to economic growth were determined by analyzing each energy source that emits $CO_2$, and the GDP. Towards this end, regression analysis was conducted. As with the method that was previously conducted, the time series of the 84-quarter period by each energy source was standardized. Table 6 shows the regression analysis results of the GDP and energy consumption based on the standardized data.

The *R*-squared value that was extracted from the regression analysis result was 0.997082, which was very significant. Moreover, the standardized regression coefficients of the different energy sources, an independent variable, were 0.245119 for coal, 0.112945 for petroleum products, and 0.162591 for LNG, showing that the consumption of these fossil fuels, which generate $CO_2$, was related to economic growth. Those of the other energy sources were very low: −0.016774 for hydro, 0.099227 for nuclear energy, and 0.438524 for the other energy sources. The analysis method that was used in this study was based on the MS-RW model so that the correlation at a specific period could be determined besides the correlation between GDP and the consumption of each energy source.

### 4.3.2. Markov switching model execution

In this section, each time series data was analyzed, using the MS-RW model, to determine the correlation between the consumption of each energy source and the GDP within a specific period. As shown in Fig. 2 and Table 7, the results of the MS-RW model execution were similar to those of the regression analysis, and it is possible to investigate more details such as the time correlation. Similar to the results of the regression analysis that were presented in the last section, while the characteristics of the three fossil fuel sources – coal, petroleum products, and LNG – differed, they were all related to economic growth. On the other hand, the hydro, nuclear, and other energy sources, which do not emit $CO_2$, were shown to be less related to economic growth, as shown by the results of the regression analysis.

Particularly, it could be concluded from the results of the MS-RW model execution, as shown in Fig. 2, that petroleum products are the energy sources that are most related to economic growth. Petroleum products were coincidental with economic growth in the 1990s while the other energy sources had little coincidence with economic growth. After 1997, the probabilities of all the energy sources and of the GDP were recorded at 0 due to the financial crisis in South Korea. Then coal, petroleum products, and LNG showed movements similar to that of economic growth.

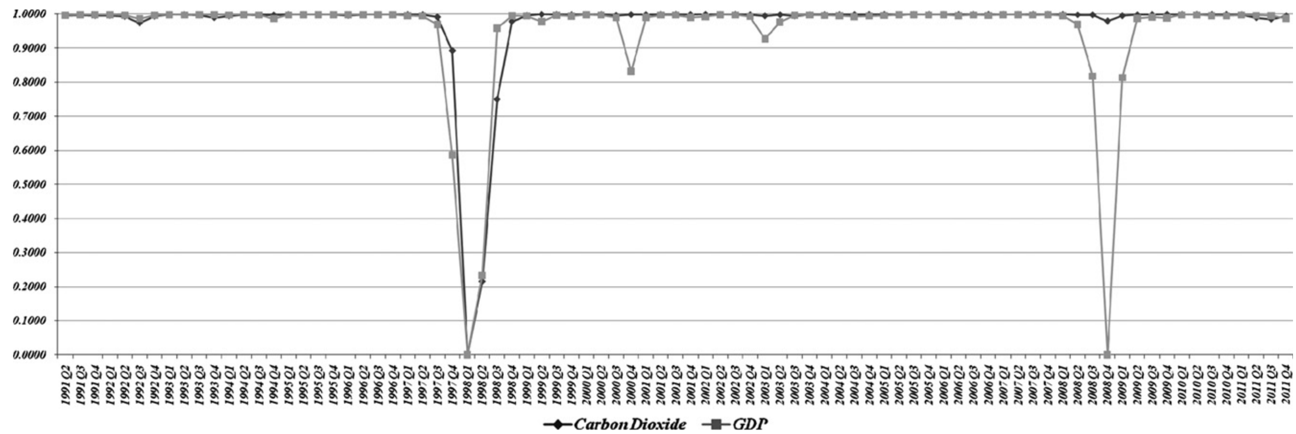


**Fig. 1.** MS-RW model result between GDP and $CO_2$ emission.

**Table 5**
Parameter estimates results of GDP and $CO_2$ emission.

| Parameter | Estimates (standard error) | |
|---|---|---|
| | GDP | $CO_2$ emission |
| $\mu_1$ | 1.4513 (0.1137) | 1.4186 (0.2500) |
| $\mu_2$ | −2.8293 (2.2596) | −5.4414 (8.5154) |
| $\sigma_1^2$ | 0.9079 (0.1584) | 4.8952 (0.8134) |
| $\sigma_2^2$ | 9.6796 (7.2072) | 141.2520 (128.5866) |
| $p_{11}$ | 0.9677 (0.0243) | 0.9847 (0.0156) |
| $p_{22}$ | 0.3999 (0.3286) | 0.4922 (0.4106) |

*Note*: $\mu_1$ = the trend in the time series of positive territory (state 1); $\mu_2$ = the trend in the time series of negative territory (state 2); $\sigma_1^2$ = variance of positive territory (state 1); $\sigma_2^2$ = variance of negative territory (state 2); $p_{11}$ = probability of transitioning from the most recent state at state 1 to the present state at state 1; $p_{22}$ = probability of transitioning from the most recent state at state 2 to the present state at state 2.

**Table 6**
Regression analysis result between GDP and energy consumption.

| Variable | Coefficient | Std. error | *t*-Statistic | Prob. |
|---|---|---|---|---|
| C | −1.884022 | 0.584348 | −3.224144 | 0.0019 |
| Coal | 0.245119 | 0.049961 | 4.906226 | 0.0000 |
| Petroleum products | 0.112945 | 0.013454 | 8.395019 | 0.0000 |
| LNG | 0.162591 | 0.049888 | 3.259127 | 0.0017 |
| Hydro | −0.016774 | 0.006608 | −2.538495 | 0.0132 |
| Nuclear | 0.099227 | 0.015254 | 6.505155 | 0.0000 |
| Other | 0.438524 | 0.059156 | 7.412965 | 0.0000 |
| *R*-squared | 0.997234 | Mean dependent var | | 49.77102 |
| Adjusted *R*-squared | 0.997019 | S.D. dependent var | | 31.30979 |
| S.E. of regression | 1.709591 | Akaike info criterion | | 3.990040 |
| Sum squared resid | 225.0479 | Schwarz criterion | | 4.192608 |
| Log likelihood | −160.5817 | Hannan–Quinn criter | | 4.071471 |
| *F*-statistic | 4627.005 | Durbin–Watson stat | | 1.053755 |
| Prob (*F*-statistic) | 0.000000 | | | |

Dependent variable: GDP; method: least squares; sample: 1991Q1 2011Q4; included observations: 84.

At this point, petroleum products were shown to be coincidental with economic growth while coal lagged behind economic growth. Although LNG coincides with economic growth, its coincidence with economic growth was inferior to that of the two other energy sources.

The parameter estimation result, based on which the characteristics of each time series data can be determined, showed that in all the time series data, except for those of LNG, the fluctuation in the rising tendency ($\sigma_1^2$) was larger than that in the falling tendency ($\sigma_2^2$). Moreover, similar to GDP, the continuity of petroleum products' rising tendency ($\sigma_1^2$) was equivalent to 0.9732, which was larger than that of the falling tendency ($\sigma_2^2$), 0.4706. Based on this result, it can be said that petroleum products, like GDP, were transformed into another state without continuing their falling tendency. On the other hand, the five other time series data, including those of coal, showed similar continuity in the rising and falling tendencies (refer to Table 7). Each energy source is consumed in different sectors. Coal, petroleum products, and LNG, which emit $CO_2$, were thus analyzed in this study.

### 4.4. Trend analysis of energy consumption by sector

#### 4.4.1. Coal

As shown in Fig. 3, coal is consumed mostly in the industrial and residential/commercial sectors. In the residential/commercial sectors, coal consumption continued to dwindle, and since after 1997, its consumption has become negligible whereas its consumption in the industrial sector has continuously increased. Accordingly, it can be said that $CO_2$ emission from coal consumption has much to do with the industrial sector.

#### 4.4.2. Petroleum products

As shown in Fig. 4, the petroleum products consumption continued to increase in all the sectors until the financial crisis in South Korea in 1997. After a slight decline in 1998 due to the financial crisis, it continued to increase, although by a small margin, in the industrial and transportation sectors whereas it decreased in the residential/commercial sectors. Therefore, it can be surmised that the increase in $CO_2$ emission from petroleum products came from the industrial and transportation sectors rather than from the residential/commercial sectors.

#### 4.4.3. LNG

As shown in Fig. 5, the biggest demand for LNG is from the residential/commercial sectors, and its consumption in the industrial sector also continues to increase. Therefore, the $CO_2$ generated by LNG can be controlled by both the residential/commercial and industrial sectors.

## 5. Results and discussions

Based on the results obtained in this study, the following correlations between South Korea's economic growth and $CO_2$ emission and between its economic growth and primary energy consumption were determined:

(1) South Korea's economic growth and $CO_2$ emission from primary energy consumption have a very close correlation.

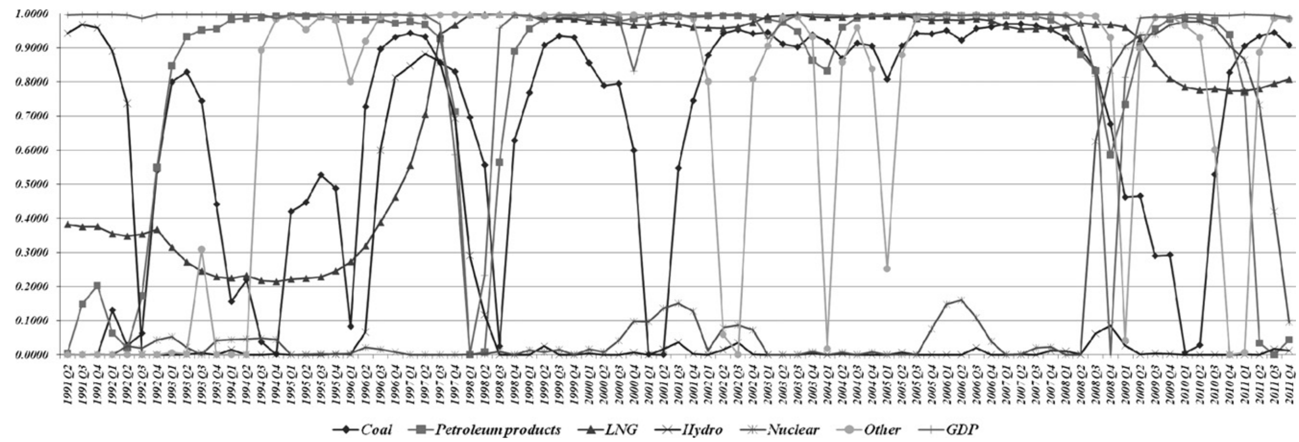


**Fig. 2.** MS-RW model result between GDP and energy consumption.

**Table 7**
Parameter estimates results of GDP and energy consumption.

| Parameter | Estimates (standard error) | | | | | | |
|---|---|---|---|---|---|---|---|
| | GDP | Coal | Petroleum products | LNG | Hydro | Nuclear | Other |
| $\mu_1$ | 1.4513 (0.1137) | 1.7212 (0.3522) | 0.8295 (0.3147) | 2.3674 (1.3712) | 2.1169 (1.7149) | 0.3099 (0.6749) | 2.8518 (0.3022) |
| $\mu_2$ | −2.8293 (2.2596) | 0.6843 (1.3189) | 0.7683 (2.5898) | 5.8668 (2.0948) | −0.0517 (0.9310) | 1.0730 (0.7763) | 2.4264 (5.3505) |
| $\sigma_1^2$ | 0.9079 (0.1584) | 4.9807 (1.4107) | 5.8645 (1.3338) | 71.4317 (15.0995) | 12.0509 (10.0159) | 3.6506 (2.3522) | 4.1254 (1.4103) |
| $\sigma_2^2$ | 9.6796 (7.2072) | 43.3121 (14.7225) | 95.2431 (41.8579) | 38.0409 (16.8788) | 373.0723 (63.7624) | 41.5628 (7.4694) | 622.1419 (203.5718) |
| $p_{11}$ | 0.9677 (0.0243) | 0.8650 (0.0703) | 0.9418 (0.0390) | 0.9806 (0.0405) | 0.8470 (0.1352) | 0.8585 (0.1492) | 0.8984 (0.0496) |
| $p_{22}$ | 0.3999 (0.3286) | 0.7562 (0.1521) | 0.8013 (0.1605) | 0.9506 (0.1203) | 0.9716 (0.0227) | 0.9757 (0.0328) | 0.7290 (0.1149) |

*Note*: $\mu_1$ = the trend in the time series of positive territory (state 1); $\mu_2$ = the trend in the time series of negative territory (state 2); $\sigma_1^2$ = variance of positive territory (state 1); $\sigma_2^2$ = variance of negative territory (state 2); $p_{11}$ = probability of transitioning from the most recent state at state 1 to the present state at state 1; $p_{22}$ = probability of transitioning from the most recent state at state 2 to the present state at state 2.

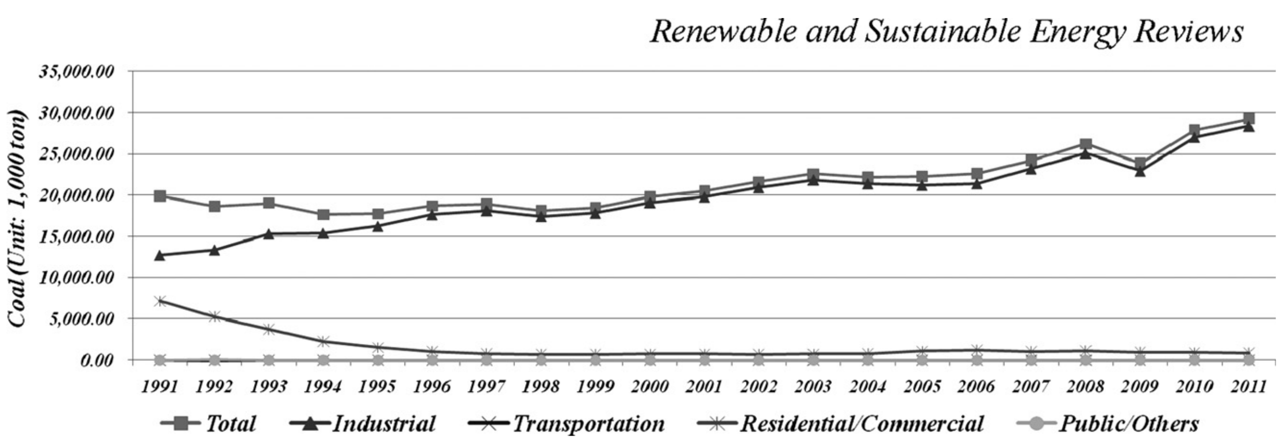


**Fig. 3.** Coal consumption trend.

The regression analysis, where GDP and $CO_2$ emission were set as dependent and independent variables, respectively, showed a standardized regression coefficient close to 1, signifying that the two move almost identically. Moreover, the time series data analysis based on a Markov switching model showed that except during the financial crisis in 2008, South Korea's economic growth and $CO_2$ emission are coincidental.

(2) For a more detailed analysis, the correlation between primary energy consumption, which was used in estimating $CO_2$ emission, and GDP was analyzed. In the regression analysis, the standardized regression coefficient of coal was the largest, followed by those of petroleum products and LNG. That of hydro was close to 0, showing that it had a slight correlation with economic growth. In terms of the Markov switching model, since after the financial crisis in 1997, coal, petroleum products, and LNG showed a coincidental movement with economic growth. Based on this result, it was observed that the energy sources related to economic growth were the fossil fuels that emit $CO_2$, such as coal, petroleum products, and LNG. In particular, petroleum products were found to be coincidental with economic growth while coal lagged behind it. LNG coincided with economic growth, but its correlation with the latter, as in the regression analysis result, was negligible.

(3) For the examination of the sectors that consume coal, petroleum products, and LNG, all of which were found to have a correlation with economic growth, the energy consumption

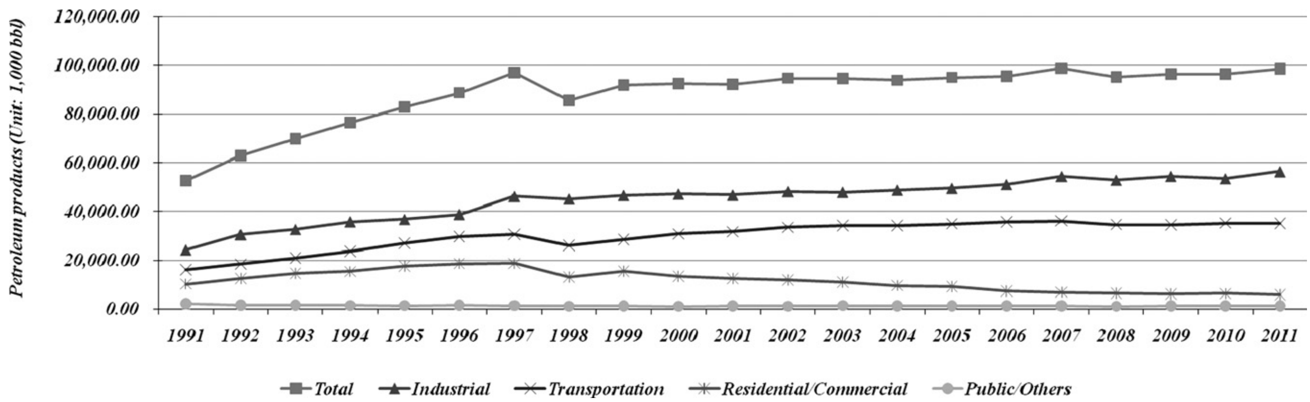


**Fig. 4.** Petroleum products consumption trend.

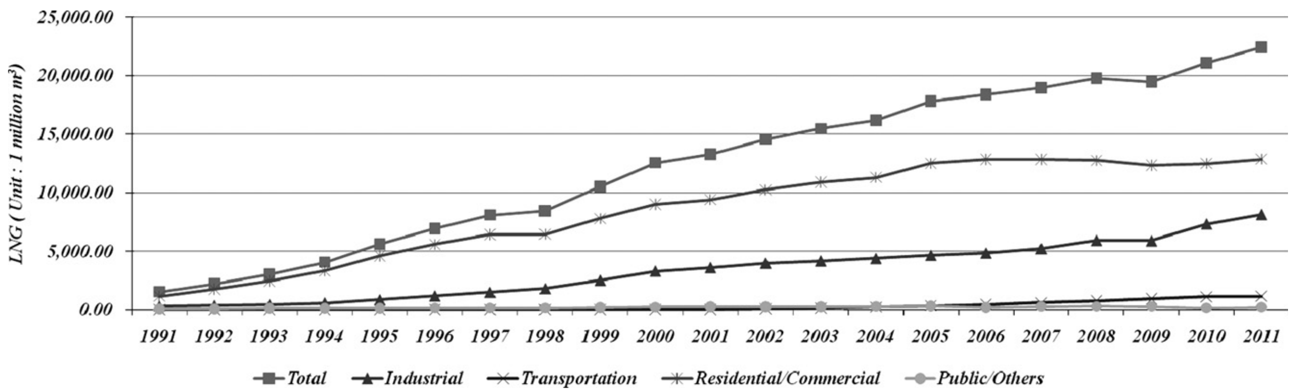


**Fig. 5.** LNG consumption trend.

trend by sector was analyzed, and the results showed that coal is mainly consumed in the industrial sector, petroleum products in the industrial and transportation sectors, and LNG in the residential/commercial and industrial sectors. Therefore, South Korea can control its $CO_2$ emission by controlling the amount of $CO_2$ emission in these sectors.

## 6. Conclusion

This paper examined the correlation among $CO_2$ emissions, energy consumption, and economic growth in South Korea from 1991 to 2011. In this study, $CO_2$ emission was estimated based on the monthly primary energy consumption to acquire sufficient time series data. Moreover, this study attempted to overcome the limitations of the existing analytical methodologies, which express the correlation among these factors only numerically and do not show their correlation at a specific period, using the MS-RW model.

Based on the results of the analysis of the data for 84 quarters, from Q1 1991 to Q4 2011, a close correlation was shown between South Korea's economic growth and its $CO_2$ emission. The results of the regression analysis showed that the country's economic growth and $CO_2$ emission were moving identically. In all the time periods that were used in this study, except during the global financial crisis in 2008, the two were observed to coincide with each other. Based on this, it was determined that whereas economic growth is affected by both internal and external factors, $CO_2$ emission is affected only by internal factors.

In the analysis of the correlation between economic growth and primary energy consumption, which was used in estimating $CO_2$ emission, it was shown that fossil fuels (coal, petroleum products, and LNG), which emit $CO_2$, were either coincidental with or lagging behind South Korea's economic growth in the periods that were included in this study. On the other hand, the energy sources that do not emit $CO_2$, such as hydro and nuclear energy, were shown to have only a slight correlation with economic growth.

Among the fossil fuels, coal was mostly consumed in the industrial sector while petroleum products and LNG were mostly consumed in the industrial/ transportation sectors and in the residential/ commercial and industrial sectors, respectively.

It is expected not only that the methodology that was used in this study will enable the proposal of $CO_2$ emission management policies for reducing energy consumption by sector, by controlling the $CO_2$ emission in the said sector, but also that the results of this study will pave the way for the proposal and establishment of strategies for reducing $CO_2$ emission nationwide and of a more advanced $CO_2$ emission management methodology.

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